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Osteometric sex determination of burned human skeletal remains

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A B S T R A C T

Sex determination of human burned skeletal remains is extremely hard to achieve because of heat-related fragmentation, warping and dimensional changes. In particular, the latter is impeditive of osteometric analyses that are based on references developed on unburned bones. New osteometric references were thus obtained which allow for more reliable sex determinations.

The calcined remains of cremated Portuguese individuals were examined and specific standard measurements of the humerus, femur, talus and calcaneus were recorded. This allowed for the compilation of new sex discriminating osteometric references which were then tested on independent samples with good results. Both the use of simple section points and of logistic regression equations provided successful sex classification scores.

These references may now be used for the sex determination of burned skeletons. Its reliability is highest for contemporary Portuguese remains but nonetheless these results have important repercussion for forensic research. More conservative use of these references may also prove valuable for other populations as well as for archaeological research.

1. Introduction

Assessing the biological profile of an individual from its burned remains is a very challenging task. The heat-induced changes (such as fragmentation) make bioanthropological analyses considerably more difficult because they restrict the use of the conventional methods usually adopted in this field.[1,2] Although the implications of this are also critical to the research of archaeological remains, this is particularly troublesome for forensic science since positive identification of victims is often only possible if focused on skeletal remains. This can occur since the soft tissues which are of great use in a number of identification methods are frequently too damaged to be of use. For example, decomposition may negate facial recognition or the use of fingerprints, while high temperatures will denature DNA.[3] As a result, forensic anthropology and forensic odontology often offer the best chances for achieving positive identification, and indeed have been quite successful in doing so in the past.[4,5]

Positive identification is based on the comparison of features using ante-mortem records but the assessment of the biological profile helps to narrow down the list of individuals included in that comparative approach. Biological profiling assumes then a significant importance in this process because the determination of sex, age-at-death, stature or ancestry will allow one to do that – through the elimination process of ineligible individuals – and thus save considerable time and resources. Determining the sex of unknown individuals is usually a straightforward procedure on unburned quite complete skeletons but the same cannot be said for burned skeletons. Besides fragmentation being particularly destructive of our more morphological sexually dimorphic bones – the pelvis and the skull – heat-induced warping and dimensional changes interfere with our conventional osteometric techniques. The latter is especially damaging because it can range from a bone expansion of 4.5% to a bone shrinkage of 40.1% depending on the type of bone, its mineralization and the temperature at which it was subject to.[2,6–11] Theoretically, this should prevent the reliable use of osteometry. Nonetheless, it has been previously demonstrated that this is not necessarily true. Several authors found that sexual dimorphism was still present in the calcined bones of adults.[12–16] As a result, it has long been argued that osteometric methods may be of some use for the analysis of burned skeletal remains.[17–21] The biggest problem

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Table 1
Age and sex composition of the sample.

Age cohort	Females	Males	Total
20–29	0	1	1
30–39	1	9	11
40–49	13	16	29
50–59	17	33	50
60–69	20	50	70
70–79	32	58	90
80–89	69	52	121
90–99	15	13	28
>100	1	0	1
Unknown	0	1	1
Total	168	233	401

seems to reside less in its potential but more in determining under which conditions those methods can be applied. It has been confirmed that heat-induced shrinkage is greatest in bones heated at temperatures leading to calcination than in bones that merely present pre-calcination burning. Therefore, osteometry should be more problematic when dealing with calcined bones.

This paper focuses on the potential of osteometry to achieve sex determination in calcined skeletons. It presents new references for the sex determination of unknown individuals through the use of standard measurements of the humerus, femur, talus and calcaneus. In order to investigate this problem, a comprehensive study was carried out at a modern crematorium. The main goal was to assess if osteometric sex determination is reliably achievable in calcined bones. If so, this would be of considerable importance for the bioanthropological analysis of burned bones because opportunities to determine sex in such cases are often rare. The usefulness for forensic cases is also obvious moreover when cremains are becoming more frequently found in such contexts. Although osteometric features should ideally maintain a supporting role in sex determination and thus leave the main role to the analysis of morphological features, the former may often be the only diagnostic features at our disposal. The validation of additional techniques for sex determination would enhance the probabilities of achieving this key parameter of the biological profile.

2. Methods

Permission was granted by the municipal authorities of Porto to collect data at the local crematorium after its legal department approved our request. The cremator was a gas-fuelled Diamond Mark III model from J.G. Shelton. The research was carried out on the calcined skeletal remains of individuals that were cremated soon after death – 24–48 h. The sample was not representative of the natural population for a number of reasons. First of all, only adults were chosen for this investigation. In addition, more skeletons from males than females were analyzed because the former tended to preserve better thus allowing for a larger number of observations.

The full sample was composed of 401 individuals (168 females and 233 males) with ages ranging from 27- to 99-years-old (mean = 71.4; sd = 15.2). About 90% of the individuals were more than 50 years-old so young adults were poorly represented. When broken down by age cohorts, the 80–89 interval was the prevalent on the female sample and the 70–79 interval was the prevalent on the male sample (Table 1).

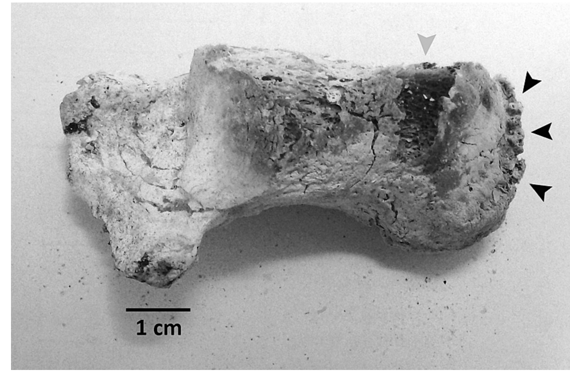

Fig. 1. Calcined calcaneus ineligible for measurement. Although it had a less than 10 mm area of black colour (grey arrow), entheseal changes (black arrows) prevented correct measurement of the maximum length.

The intensity of combustion was recorded for every cremation and the descriptive statistics according to three age cohorts are given in Table 2. The duration of the cremation of cadavers ranged between 50 and 250 min (mean = 93.8). The maximum temperature of the cremations ranged between 750 °C and 1050 °C (mean = 925.8). The statistics presented in Table 2 do not include 160 individuals because, in these cases, the cremation procedure was somewhat more intricate thus complicating its codification in terms of the duration of the combustion. More specifically, an important part of the cremation was carried out while the cremator was switched off and taking advantage of the heat that had been previously accumulated inside the chamber. This allowed for the completion of the cremation without resorting to any additional fuelling. Given this, such cremations benefiting from this procedure were not used to calculate the mean durations and maximum temperatures of combustion. The latter was recorded by using 25 °C increments.

Only bones free of major osteoarthritic alterations in joint contour and major entheseal changes of the calcaneal tendon and of the distal humerus were measured after cremation (Fig. 1). This was done because these alterations are susceptible to interfere with dimensions. In addition, only the measurements carried out on bones presenting the typical colours of calcination – white, light grey and light blue[9,22] – on more than 90% of its surface were selected for this investigation (Figs. 1 and 2). Bones were subjected to three measurements with a digital calliper and the median value was then recorded in millimetres. The standard measurements included the transverse and vertical head diameters of the humerus (HHTD and HHVD), the epicondylar breadth of the humerus (HEB) and the transverse and vertical head diameters of the femur (FHTD and FHVD) as defined by Martin and Saller.[23] In addition, the maximum lengths of the talus and the calcaneus (TML and CML) as defined

Table 2
Descriptive statistics for the intensity of combustion according to sex and age cohort.

Age	n	Duration ♀		Temperature ♀		n	Duration ♂		Temperature ♂	
		Mean	SD	Mean	SD		Mean	SD	Mean	SD
0–59	21	99.3	19.8	885.7	67.8	41	98.9	23.0	931.7	72.7
60–79	29	92.8	24.4	914.7	62.9	61	95.7	27.8	934.8	68.1
≥80	54	86.0	21.4	921.8	57.9	35	94.0	21.6	942.1	51.7

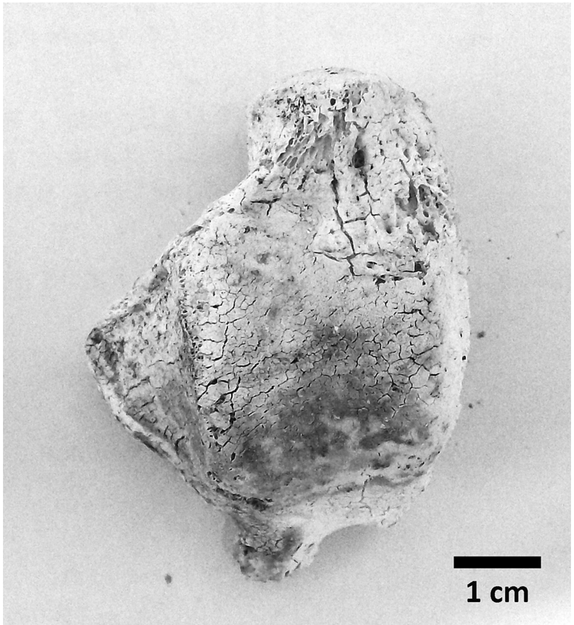

Fig. 2. Calcined talus eligible for measurement. The blackish areas were caused by charcoal staining and did not refer to the actual bone colour.

Table 3
Intra-observer variation results for the calculation of the technical error of measurement (TEM).

Standard measurements	TEM (mm)	%TEM	R
Humeral head transverse diameter	0.16	1.14	0.999
Humeral head vertical diameter	0.23	1.76	0.996
Humeral epicondylar breadth	0.14	0.94	0.999
Femoral head transverse diameter	0.12	0.78	0.999
Femoral head vertical diameter	0.17	0.84	0.999
Talar maximum length	0.13	0.91	0.999
Calcaneal maximum length	0.14	0.45	0.999

by Silva[24] were also included. The selection of the standard measurements used in this research followed two main criteria. Firstly, measurements focusing on spongy bone were chosen because this tends to preserve better than compact bone when subject to heat. Secondly, sex discriminating features with associated success rates over 80% were selected in Portuguese populations. That is the case for the abovementioned humeral and femoral measurements[25] and for the talar and calcaneal measurements.[24]

The intra-observer variation regarding each standard measurement was determined by calculating the technical error of measurement (TEM) on samples of 20 bones.[26] Inter-observer variation was not assessed because only one of the authors was present daily at the crematorium. Nonetheless, the standard measurements used in the present research are extensively used by bioanthropologists and theoretically do not raise many replicability problems.

Bilateral asymmetry was investigated in order to determine if left and right measurements presented no significant differences and thus dispense the analysis of both sides. This analysis was not carried out for the humeral epicondylar breadth because the sample size was not sufficient. Sexual dimorphism was investigated on a sub-sample of 370 individuals (154 females and 216 males). For all features, an equal number of females and males was used. The sex-pooled mean values obtained for each standard measurement were used as cut-off points for the sex discrimination of an independent test-sample of calcined skeletons. This was done with the aim of avoiding any possible bias resulting from carrying out the test on the same sample from which the mean values were obtained. In addition, logistic regression equations were also created and tested on an independent test-sample. Logistic regression allows for the analysis and prediction of a dichotomous variable. It is more robust than discriminant function analysis and its use does not require normal distribution of the factors or the equality of variance-covariance matrices in the sub-samples – which in this case, refer to the two sex groups.[27,28] The amount of individuals composing the test-samples varied between each standard measurement due to differential preservation of the diagnostic features. Most were mainly composed of males rather than females due to poorer post-cremation preservation of the latter.

All statistical analyses were carried out by using the Statistical Package for the Social Sciences (SPSS, version 14.0).

3. Results

The absolute TEM for the intra-observer measurements ranged between 0.12 and 0.23 mm while the relative TEM ranged between 0.45% and 1.76% (Table 3). The coefficient of reliability was of 0.99 for all standard measurements indicating that only a small portion of the measurement variance present in the sample was the result of measurement error. These results demonstrated good repeatability of observations.

Right and left bones were not significantly different at the 0.05 level (Table 4). The exception was the femoral head vertical diameter but even in this case the difference between antimeres was

Table 4
Mean differences between left and right bones.

Std. measurement	Side	*n*	Mean	SD	Median	Range	Test	Sig
Humeral head transverse diameter	Left	17	37.99	2.98	–	–	0.258[a]	0.800
	Right	17	37.92	3.18	–	–		
Humeral head vertical diameter	Left	41	42.43	3.00	–	–	−0.006[a]	0.995
	Right	41	42.43	2.85	–	–		
Femoral head transverse diameter	Left	12	38.69	3.40	39.56	9.72	−0.314[b]	0.754
	Right	12	38.99	3.60	39.26	9.84		
Femoral head vertical diameter	Left	33	41.53	3.32	40.66	13.66	−1.983[b]	0.047
	Right	33	42.02	3.15	41.52	14.28		
Talar maximum length	Left	11	48.77	5.01	46.29	13.91	−0.445[b]	0.657
	Right	11	48.99	4.60	49.04	13.94		
Calcaneal maximum length	Left	10	72.38	8.53	71.19	28.03	−1.070[b]	0.285
	Right	10	73.40	6.82	72.94	20.73		

[a] *t*-Test.
[b] Wilcoxon signed ranks test.

Table 5
Descriptive and inferential statistics for the humerus, femur, talus and calcaneus.

Standard measurement	Sex	n	Mean	S.D.	t	df	Sig.	d
Humeral head transverse diameter	Female	33	33.76	2.82	−9.03	64	0.000	2.25
	Male	33	39.16	1.97				
	Pooled	66	36.46	3.64				
Humeral head vertical diameter	Female	62	37.74	2.98	−10.93	122	0.000	1.97
	Male	62	43.51	2.89				
	Pooled	124	40.63	4.11				
Humeral epicondylar breadth	Female	25	50.48	3.35	−7.88	48	0.000	2.23
	Male	25	58.32	3.67				
	Pooled	50	54.40	5.27				
Femoral head transverse diameter	Female	42	35.87	2.08	−9.49	82	0.000	2.09
	Male	42	40.95	2.77				
	Pooled	84	38.41	3.53				
Femoral head vertical diameter	Female	55	37.64	2.18	−9.99	108	0.000	1.20
	Male	55	43.02	3.34				
	Pooled	110	40.33	3.89				
Talar maximum length	Female	30	45.57	2.93	−6.88	58	0.000	1.76
	Male	30	50.97	3.15				
	Pooled	60	48.27	4.06				
Calcaneal maximum length	Female	47	67.71	3.95	−10.656	92	0.000	2.20
	Male	47	76.92	4.42				
	Pooled	94	72.31	4.06				

small – only 0.51 mm with an associated TEM of 0.12 mm. Therefore, the measurements from the right side were selected for the analysis regarding sexual dimorphism and the dimensions of left-sided bones were only used when the right ones were absent. This approach was also followed for the humeral epicondylar breadth although the bilateral asymmetry was not investigated in this case due to small sample sizes. However, and given the results obtained for the other standard measurements, it was assumed that the same outcome was also to be expected in this particular case.

Significant differences at the 0.01 level were found between females and males in all standard measurements (Table 5). The effect size was very large according to Cohen.[29] The use of the sex-pooled mean values as sex discriminating cut-off points was very successful in all cases but the talar maximum length (Fig. 3). The latter was the only one not allowing for correct sex classification above 80%. In this case, although females were correctly identified in all cases, only 75% of the males were attributed to their proper sex.

As for the logistic regression equations (Table 6), this method also allowed sex classification scores over 80% while using any standard measurement (Fig. 4). The investigation regarding the combination of two measurements was carried out for both the humerus and the femur. In the first case, the sample was composed of 26 females and 28 males (Table 7). When considered together, the transverse and vertical humeral head diameters significantly predicted whether or not an individual was a male ($\chi^2 = 43.03$; df = 2; $n = 54$; $p < 0.001$). This model correctly predicted the sex of all females ($n = 10$) and males ($n = 10$) in an independent test-sample. In the case of the femur, the sample was composed of 32 females and 37 males (Table 7). When considered together, the transverse and vertical head diameters significantly predicted if an individual was a male or not ($\chi^2 = 56.17$; df = 2; $n = 69$; $p < 0.001$). The testing of the equations on an independent sample was successful for 90% of both the females ($n = 10$) and males ($n = 10$). No other logistic models were tested due to the small size of the samples.

4. Discussion

The present results confirmed that sexual dimorphism was still present in calcined bones despite heat-induced dimensional changes. This significant difference was sufficient to allow for the correct sex classification of most individuals although not all diagnostic features were equally successful. The maximum length

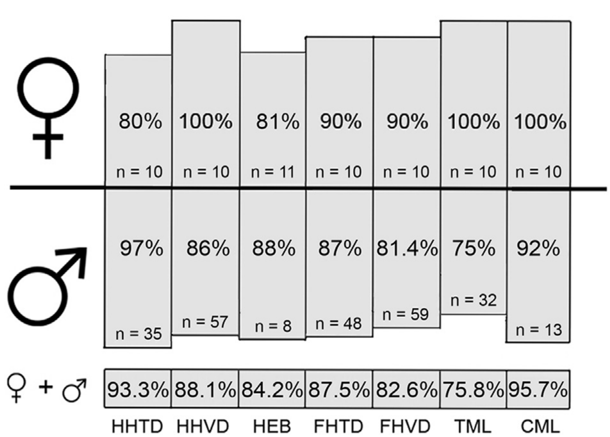

Fig. 3. Correct sex classification of the independent test-sample using the cut-off points. n refers to the amount of individuals composing the test-sample.

Table 6
Coefficients for the logistic regressions according to each standard measurement. Example for sex determination using the humeral head transverse diameter: $L = -32.753 + 0.891$*HHTD.

Standard measurement	β	Se	Odds ratio	Sig.
Humeral head transverse diameter	0.891	0.213	2.437	0.000
Constant	−32.753	7.878	0.000	0.000
Humeral head vertical diameter	0.661	0.111	1.937	0.000
Constant	−26.919	4.545	0.000	0.000
Humeral epicondylar breadth	0.904	0.270	2.469	0.001
Constant	−49.415	14.90	0.000	0.001
Femoral head transverse diameter	0.782	0.160	2.187	0.000
Constant	−29.896	6.105	0.000	0.000
Femoral head vertical diameter	0.759	0.142	2.137	0.000
Constant	−30.376	5.663	0.000	0.000
Talar maximum length	0.683	0.175	1.980	0.000
Constant	−32.849	8.421	0.000	0.000
Calcaneal maximum length	0.549	0.111	1.732	0.000
Constant	−39.628	8.018	0.000	0.000

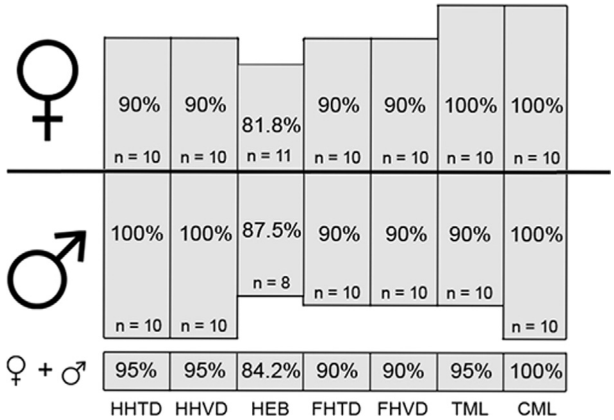

Fig. 4. Correct sex classification of the independent test-sample using the logistitic regression equations. *n* refers to the amount of individuals composing the test-sample.

Table 7
Coefficients for the humerus and femur logistic models. Example for sex determination using humeral measurements: $L = -37.626 + 0.825*HHTD + 0.177*HHVD$.

Standard measurement	β	Se	Odds ratio	Sig.
Humeral head transverse diameter	0.825	0.302	2.28	0.006
Humeral head vertical diameter	0.177	0.217	1.19	0.415
Constant	−37.626	10.732	0.000	0.000
Femoral head transverse diameter	0.664	0.274	1.94	0.015
Femoral head vertical diameter	0.299	0.246	1.35	0.225
Constant	−36.860	8.840	0.000	0.000

of the calcaneus was the most sex discriminating feature for both approaches using the millimetric cut-off points and the logistic regression equations. The maximum length of the talus was not very successful while using the first approach but allowed for better sex classification scores when using logistic regression. The combination of two standard measurements (HHTD and HHVD) into a logistic model resulted in additional accuracy regarding the sex classification of the test-samples while using the humeral features. In the case of the femur, no additional accuracy was documented by combining FHTD and FHVD into one logistic model.

The findings demonstrated that osteometric sex determination is not impeded by heat-induced dimensional changes of calcined bone. Therefore, this research confirms what was already determined previously by other investigations such as the ones from Van Vark et al.[14] and Wahl.[15] Rather than due to the elimination of sexual dimorphism, part of the problem of using osteometry stands on the lack of references from which reliable assessments may be carried out. Another problem is to decide when those references should be used since heat-induced dimensional changes may be extremely variable. In this research, we relied on the colour of burned bone to select calcined specimens. This criterion was very easy to use. As a result, possible differential heat-induced shrinkage between calcined bones was not sufficient to eradicate sexual dimorphism. It is worth noticing once again that our results were obtained on a sample mostly composed of very aged individuals so we do not know if the chromatic criterion would be as successful if the sample presented a different age composition.

Another difficulty regarding the use of diagnostic features is related to the fragmentation often present on burned skeletal remains. In this research, the remains of 118 individuals were thoroughly examined and at least one measurable feature was preserved in 92 (78%) of them. Worse preservation might be likely to occur for cremains from forensic and archaeological contexts but some applicability of osteometric methods may nonetheless be expected.

It is possible that population differences prevent these osteometric references to be used on other than western European individuals or even other than Portuguese individuals. The mean dimensions of the humeral and femoral vertical head diameters of Swedish and American samples that were obtained on previous investigation[14,30] were indeed larger than the Portuguese ones (Table 8). Although those studies were carried out several years before ours, the mean stature of both the Swedish[31] and American[30] populations was at the time already larger than the mean stature of present-day Portuguese – as was documented in those very same investigations. That may in part explain why Portuguese bone dimensions are smaller than both. However, the comparison is not so straightforward if Swedish and American samples are compared against each other. Although the latter present higher stature for both females and males, Swedish have larger bone dimensions in three out of four standard measurements. Both samples are similarly aged, therefore this is a somewhat unexpected result. Other than stature, activity patterns, differential shrinkage or any other unknown factor may then be in the origin of the differences that have been documented. This suggests that osteometric references are population-specific, but the data presented in Table 8 may not be completely comparable because the Portuguese values are indirectly inferred from Barroso et al.[32] whose sample was mainly composed of industrial workers with ages ranging from 17- to 65-years-old.

The observations were carried out on a large sample but the sub-samples referring to each standard measurement were regrettably much smaller. Although some were indeed composed of a large number of bones – HHVD, FHTD, FHVD and CML – the others presented smaller sub-samples. All allowed for the calculation of sex-pooled means and/or logistic regression coefficients that led to good sex classification scores but the compilation of larger assemblages would have been advisable. This was not done due to time constraints. The same can be said about the test-samples, especially those referring to females. Larger samples would have allowed for more reliable testing. Even so, it is our understanding that the present test-samples provided good indication of the potential of our osteometric references for calcined bones.

Several authors stated that osteometry has a limited potential for the analysis of burned skeletal remains.[1,3,6,20,21,32,33] This is still somewhat true but the present research demonstrated that sex can be osteometrically determined from calcined bones thus following the findings of previous investigations.[10,12,14,34–36] Although the examination of morphological features should be preferentially used for sex determination, heat-related fragmentation of bone

Table 8
Mean stature and mean dimensions for the head vertical diameters of the humerus (HHVD) and the femur (FHVD) in function of sex (values in mm). The Portuguese mean statures were obtained from Barroso et al.[32]

	Age ♂	Stature ♂	HHVD ♂	FHVD ♂	Age ♀	Stature ♀	HHVD ♀	FHVD ♀
Portuguese	17–65	1690 ($n = 492$)	43.51 ($n = 62$)	43.02 ($n = 55$)	17–65	1565 ($n = 399$)	37.74 ($n = 62$)	37.64 ($n = 55$)
Swedish	Mean: 68	1716 ($n = 100$)	44.10 ($n = 104$)	45.90 ($n = 104$)	Mean: 73	1579 ($n = 101$)	38.71 ($n = 98$)	39.96 ($n = 99$)
American	Mean: 66	1761 ($n = 51$)	45.80 ($n = 28$)	44.20 ($n = 17$)	Mean: 75	1604 ($n = 41$)	38.16 ($n = 10$)	38.10 ($n = 6$)

often prevents this multivariate approach. As a result, osteometric methods may then assume an important role in these cases.

Conflict of interest

The authors state that they do not have any conflict of interest whatsoever. The present research was not biased by any people or organization.

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Ethical approval

None.

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